Advanced Reliability Studies on III-V HEMTS using Low Frequency Noise Spectroscopy.

Electrical Characterization Task

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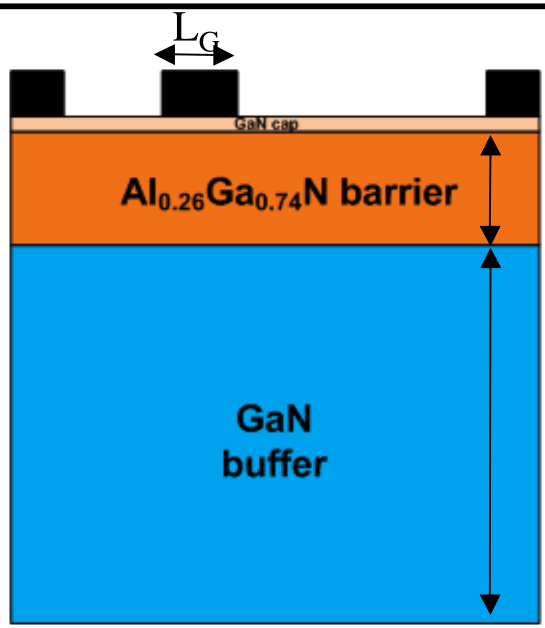
Outline

- Device under study
- DC Characterization
- Noise measurement setup
- Drain noise characteristics
  - Noise sources
  - Noise mechanism
- Gate noise characteristics
  - Noise sources
  - Drain and gate correlation
  - Noise mechanism
- Summary

Device under study



STRUCTURE

GaN cap layer thickness = 15 Å

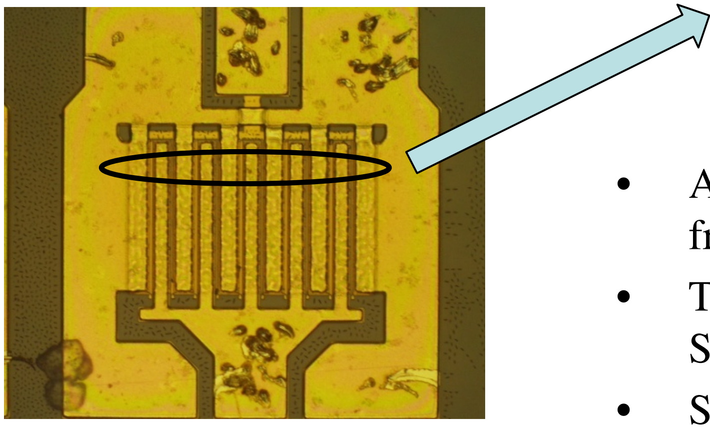
AlGaN barrier thickness (d) = 180 Å

GaN buffer thickness = 8000 Å

Gate Width (W_G) = 200 µm

Gate length (L_G) = 0.65 µm

- Gate Fingers = 10
- Gate periphery = 2 mm (10 x 200 µm)



PROCESS

- AlGaN/GaN grown by MOCVD with Aluminum mole fraction (x) = 26%
- Ti/Al Source-Drain Ohmic contacts and Ni/Au Schottky Gate contact formed by RTA
- SiN passivation deposited by PECVD

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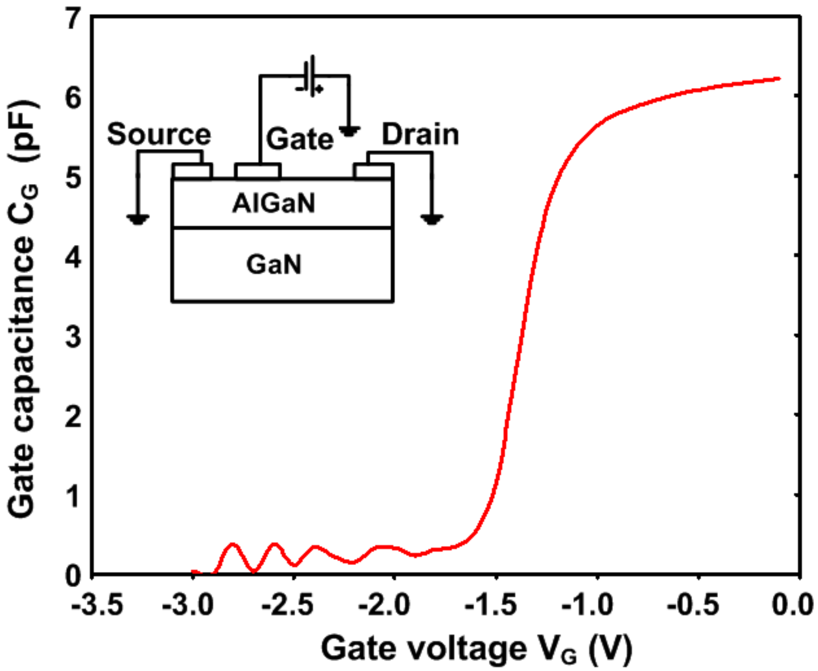
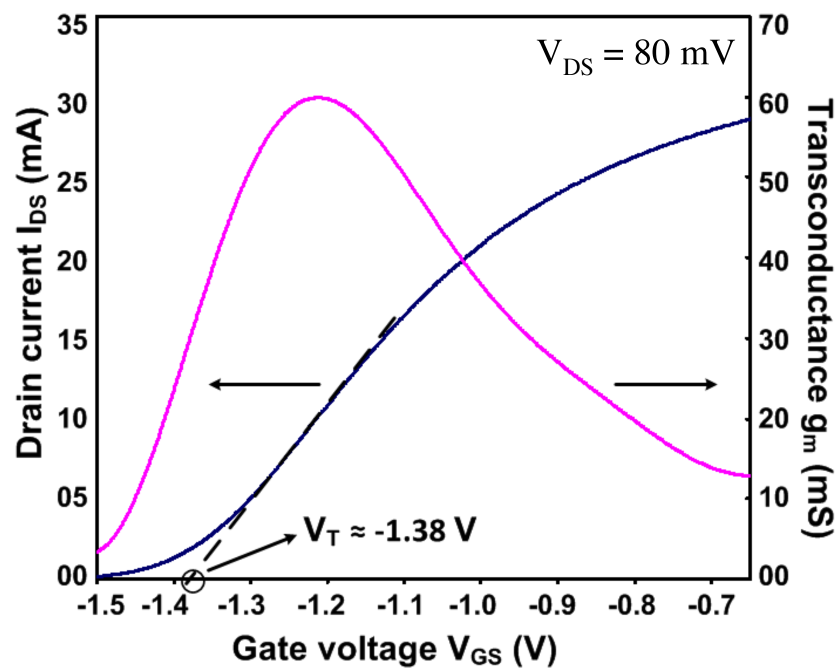
DC Characterization

Gate C-V



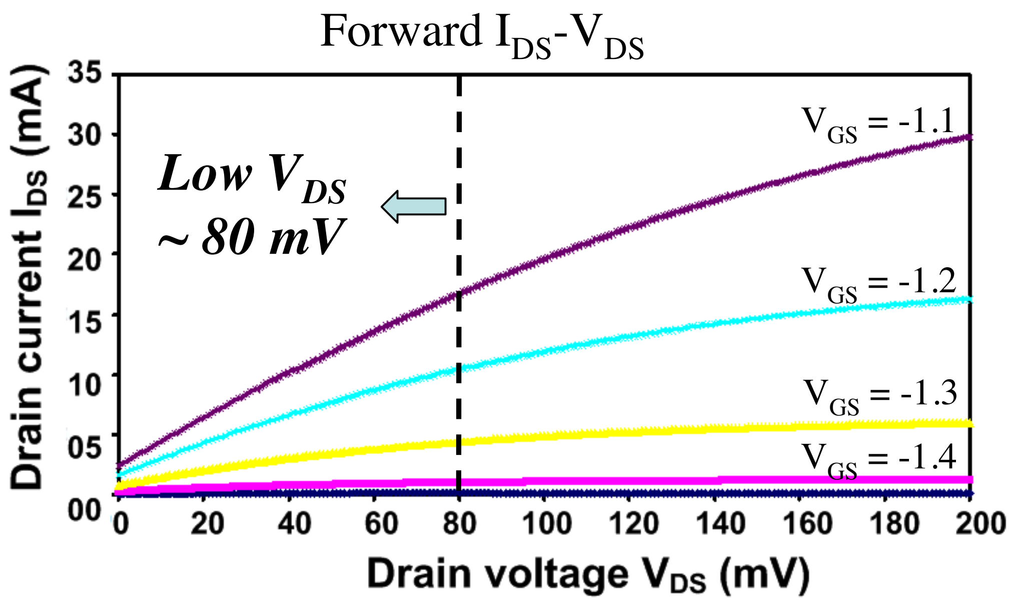
Transconductance

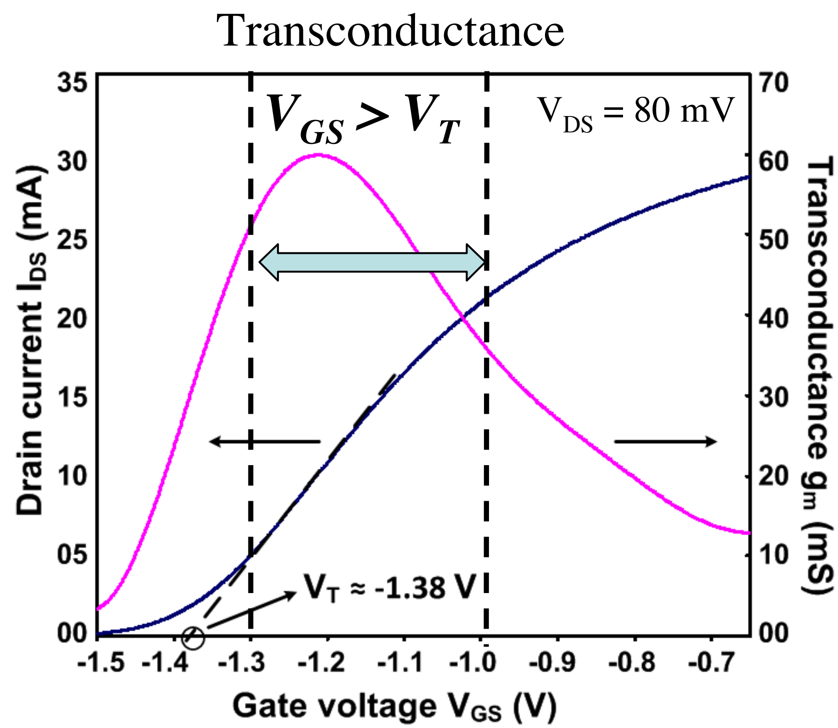


- Field effect mobility (μ_N) values between 180 to 415 cm^2/V-s for sheet carrier density (n_S) of 10^{11} to 10^{12} cm^{-2}.

$$\mu_N = \frac{L_G}{q n_S(V_G) W_G R_{CH}} \text{where,} \qquad n_S(V_G) = \frac{1}{q}\int_{V_P<V_T}^{V_G} C\,dV_G$$

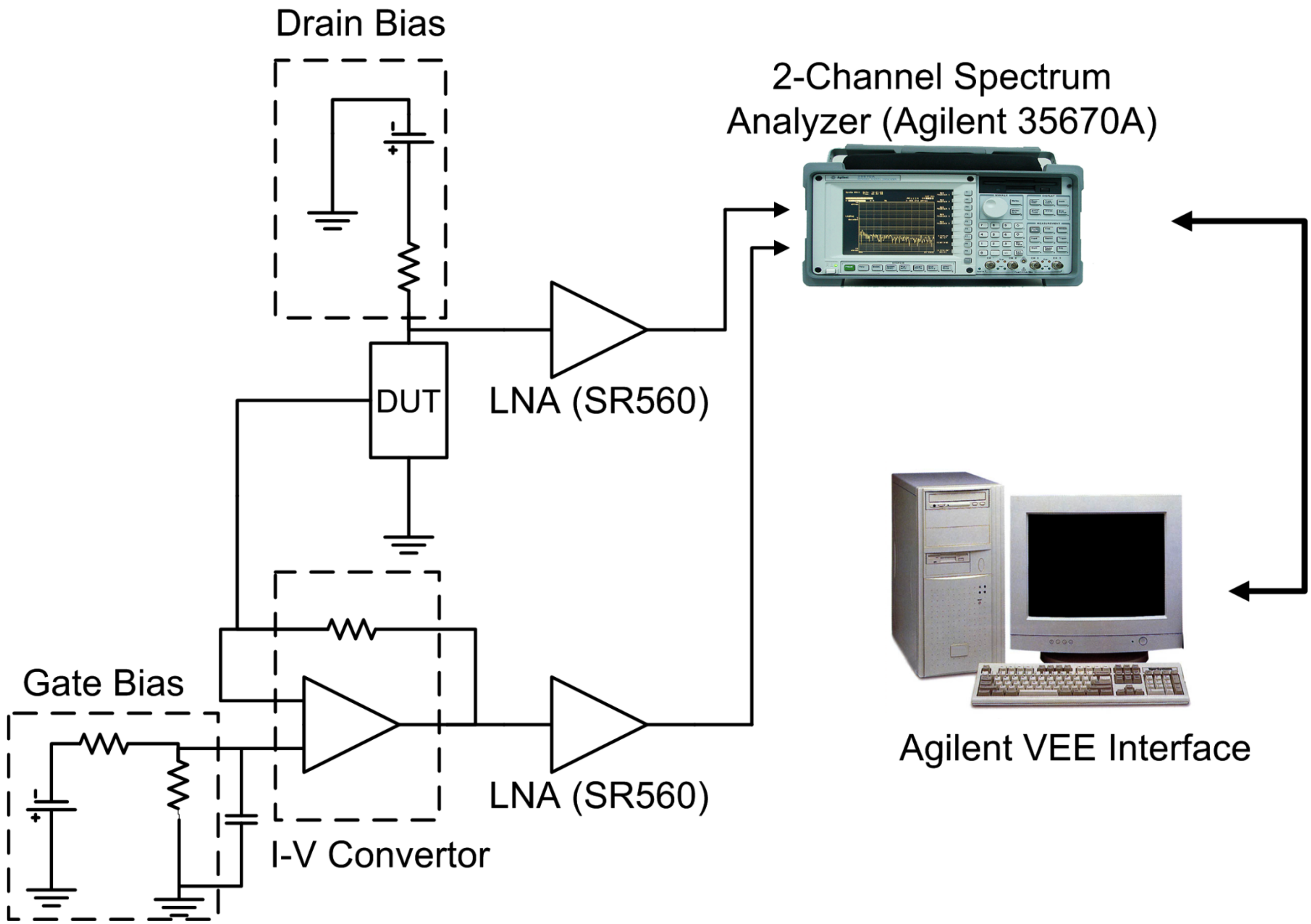
Noise bias regime





- Device connected in common source configuration.
- Noise measured at *low drain bias* of V_{DS} = 80 mV and *low drain current* I_{DS} < 25 mA

Noise Measurement Setup



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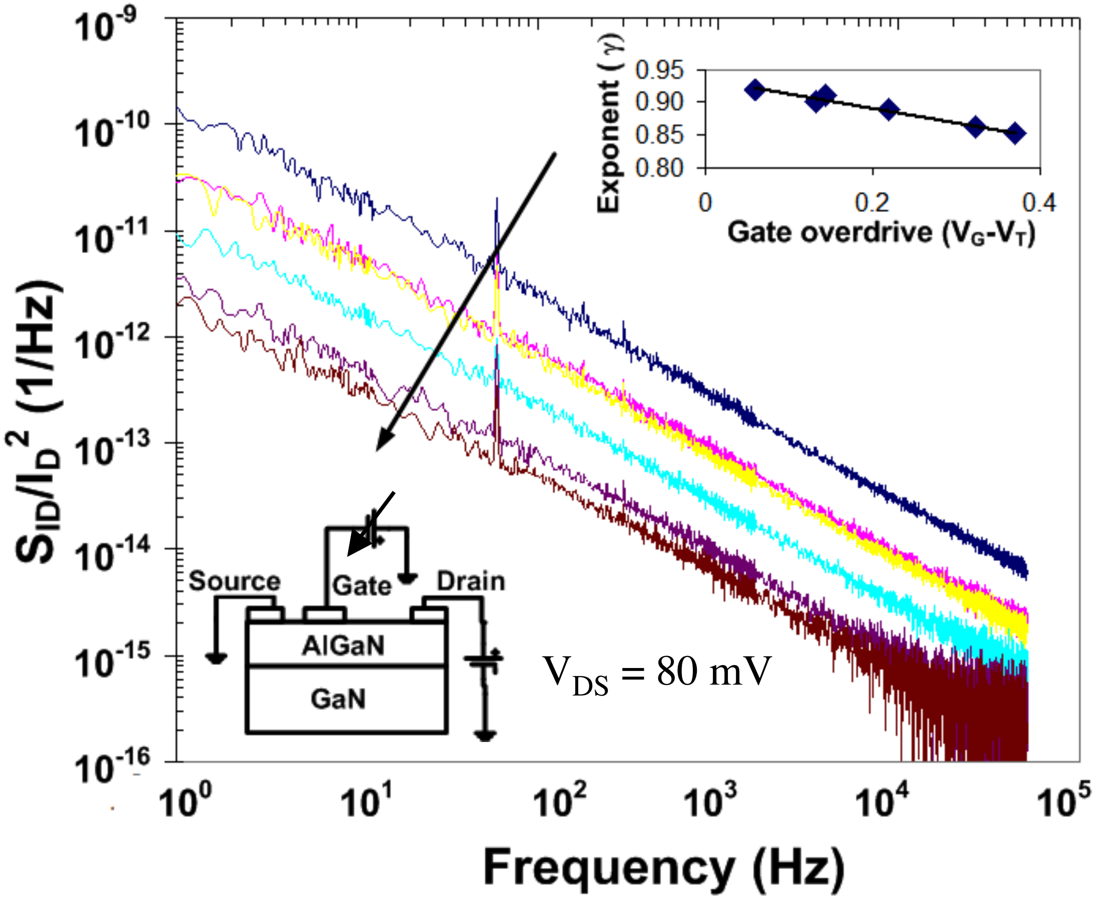
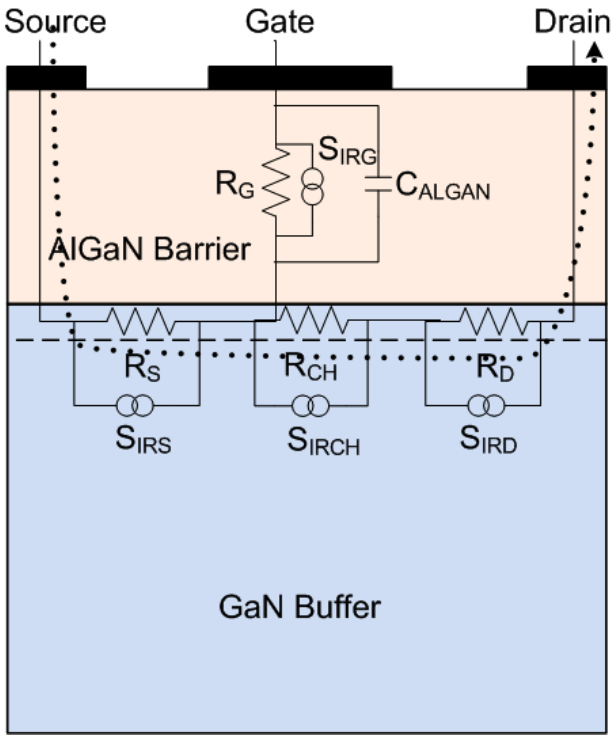
Drain noise characteristics



- Drain noise measured as a function of V_{GS} for constant low V_{DS}
- Frequency exponent (γ) is a inverse function of the gate overdrive voltage.
- Indicator of non-uniform trap distribution. High band-bending in AlGaN barrier creates a trap distribution skewed towards the interface leading to high frequency traps.
- No distinct generation-recombination components at room temperature.

Noise sources



$$\frac{S_{ID}}{I_D^2} = \frac{S_{RCH}}{R_{CH}^2}\left(\frac{R_{CH}^2}{(R_S + R_D + R_{CH})^2}\right) + \frac{S_{RD}}{R_D^2}\left(\frac{R_D^2}{(R_S + R_D + R_{CH})^2}\right)$$

$$+ \frac{S_{RS}}{R_S^2}\left(\frac{R_S^2}{(R_S + R_D + R_{CH})^2}\right)$$

Case I: $R_{CH} > (R_S + R_D), S_{R_{CH}} > (S_{R_S} + S_{R_D})$

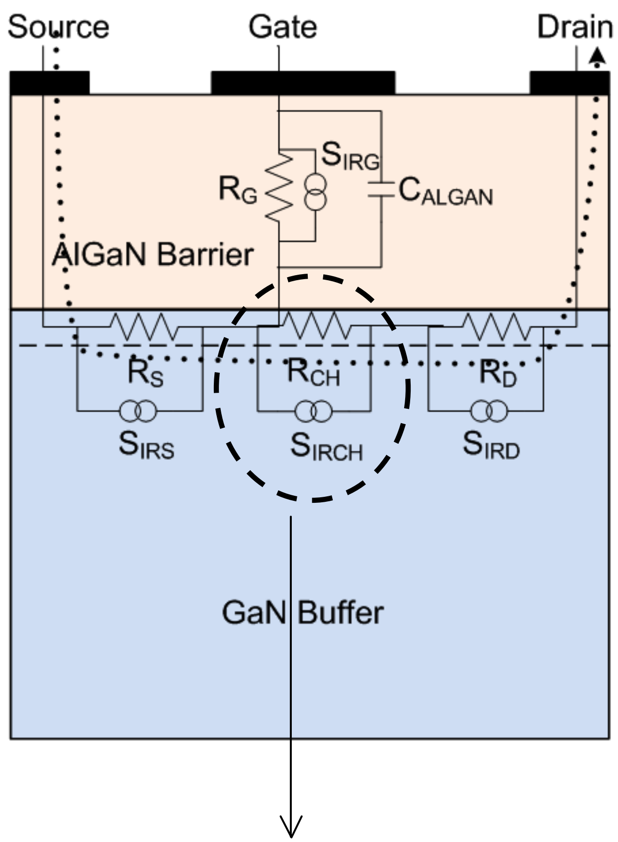
$$\frac{S_{I_D}}{I_D^2} \cong \frac{S_{R_{CH}}}{R_{CH}^2} \cong \frac{\alpha_{CH}}{N_{CH} f} \propto V_G^{-1}$$

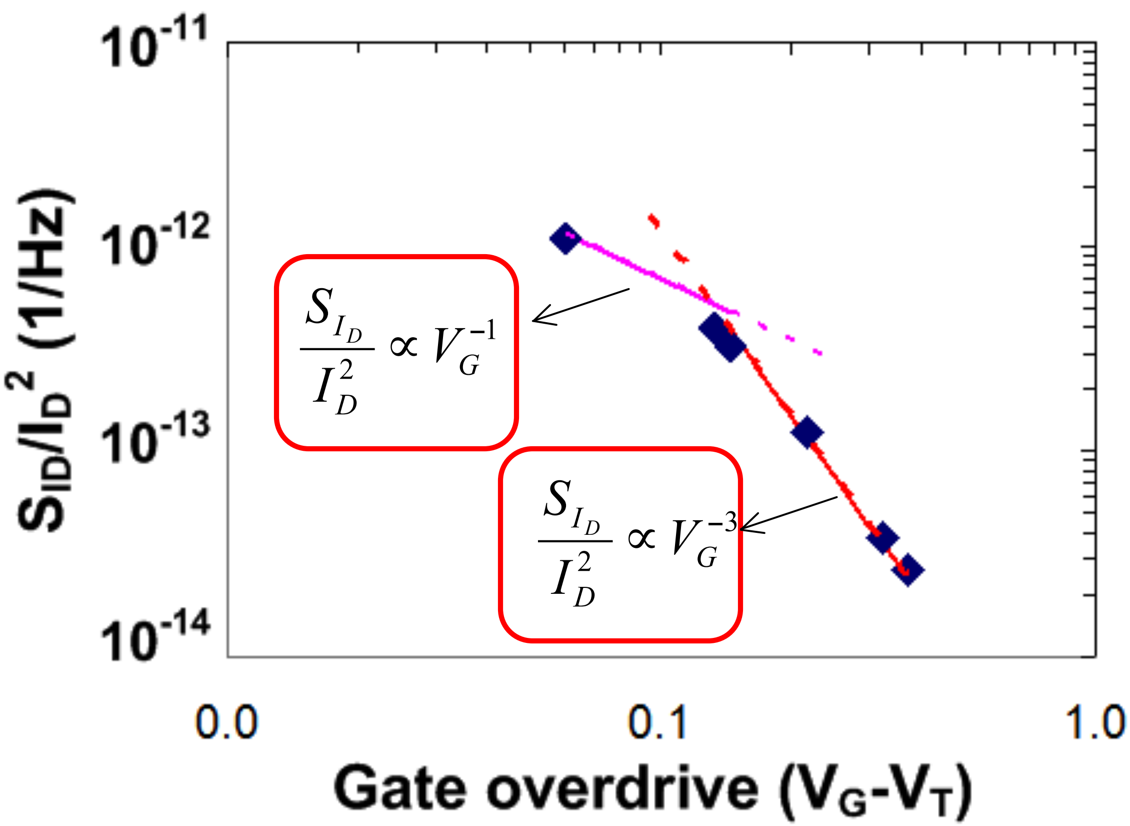
Case II: $(R_S + R_D) > R_{CH}, S_{R_{CH}} > (S_{R_S} + S_{R_D})$

$$\frac{S_{I_D}}{I_D^2} \cong \frac{S_{R_{CH}}}{R_A^2} + \frac{S_{R_A}}{R_A^2} \cong \frac{S_{R_{CH}}}{R_A^2} = \frac{\alpha_{CH}}{N_{CH} f} \times \left(\frac{R_{CH}}{R_A}\right)^2 \propto V_G^{-3}$$

Where, $R_A = R_S + R_D, S_{R_A} = S_{R_S} + S_{R_D}$

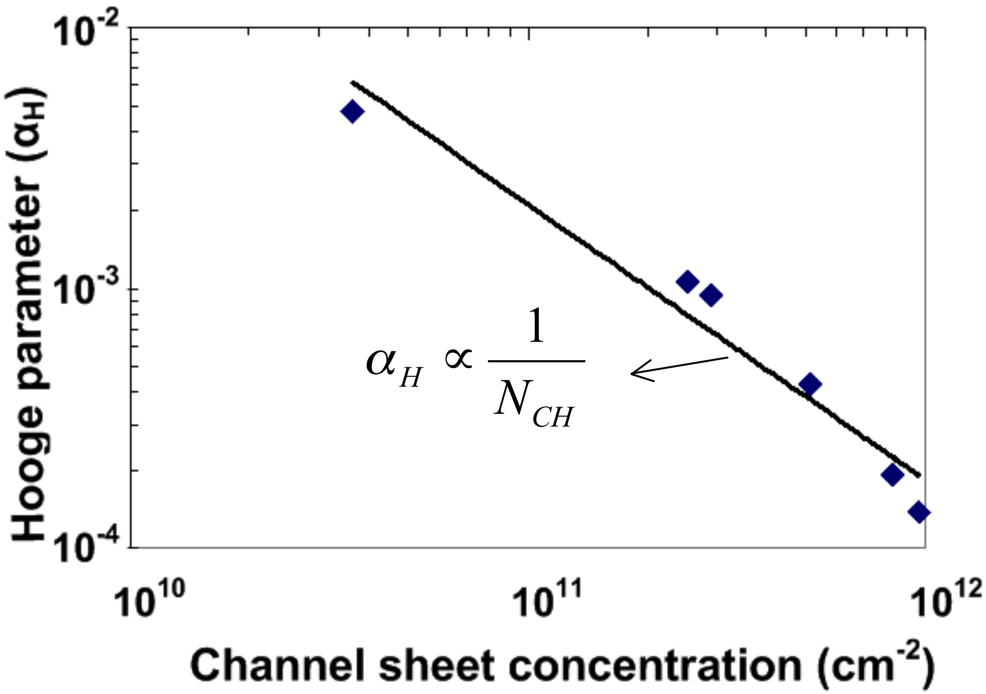
Measured noise gate dependence

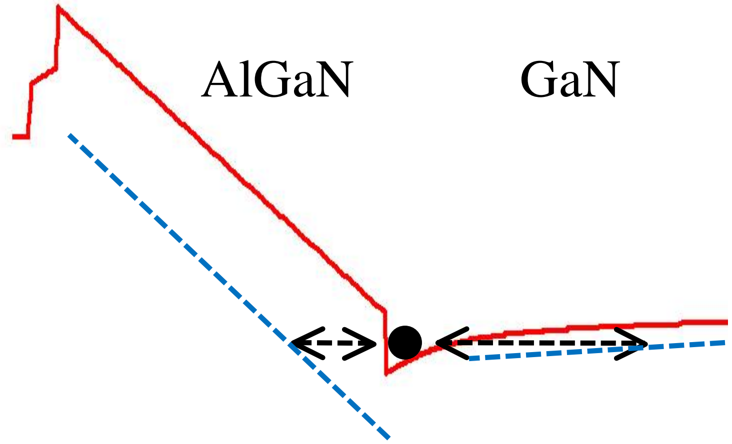




Channel is the dominant noise source !!

Noise mechanism





Associated with Δn model [*]

$$S_{I_D}(f) = \frac{q\mu_n \alpha_H I_D V_D}{L_G^2 \, f} \Rightarrow \alpha_H = \frac{S_{I_D}(f) L_G^2 \, f}{q\mu_n I_D V_D}$$

- High quality ohmic contact.
- Channel $\alpha_H \sim 10^{-3} - 10^{-4}$ stable but relatively noisy.

[*] L.K.J. Vandamme and R.G.M. Penning de Vries, Solid-State Electronics **28**, 1049-1056 (1985).

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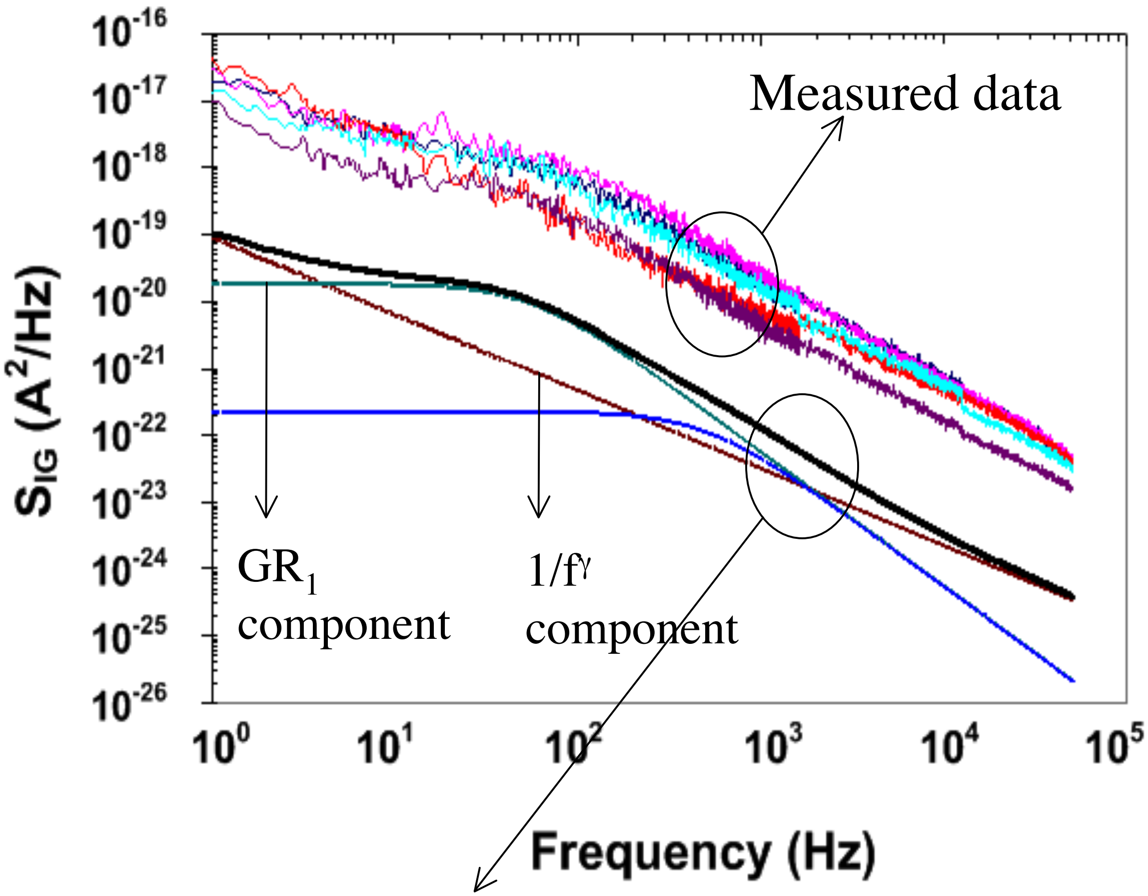
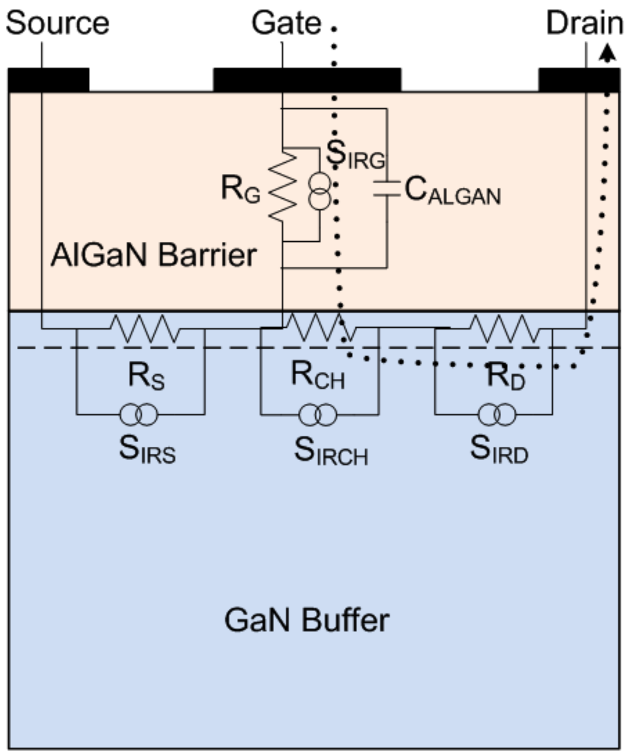
Gate current noise



- Noise measured in the triode region at low V_{DS} = 80 mV
- Simultaneously measured with drain current noise.
- Background $1/f^{\gamma}$ noise.
- Lorentzian components on top indicate a trap related mechanism in the gate stack

$$S_{I_G}(f) = S_{1/f}(f) + \sum S_{GR}(f)$$

Noise sources



$$\frac{S_{I_G}}{I_G^2} = \frac{S_{R_G}}{R_G^2}\left(\frac{R_G^2}{(R_G + R_D + R_{CH})^2}\right) + \frac{S_{RCH}}{R_{CH}^2}\left(\frac{R_{CH}^2}{(R_G + R_D + R_{CH})^2}\right)$$

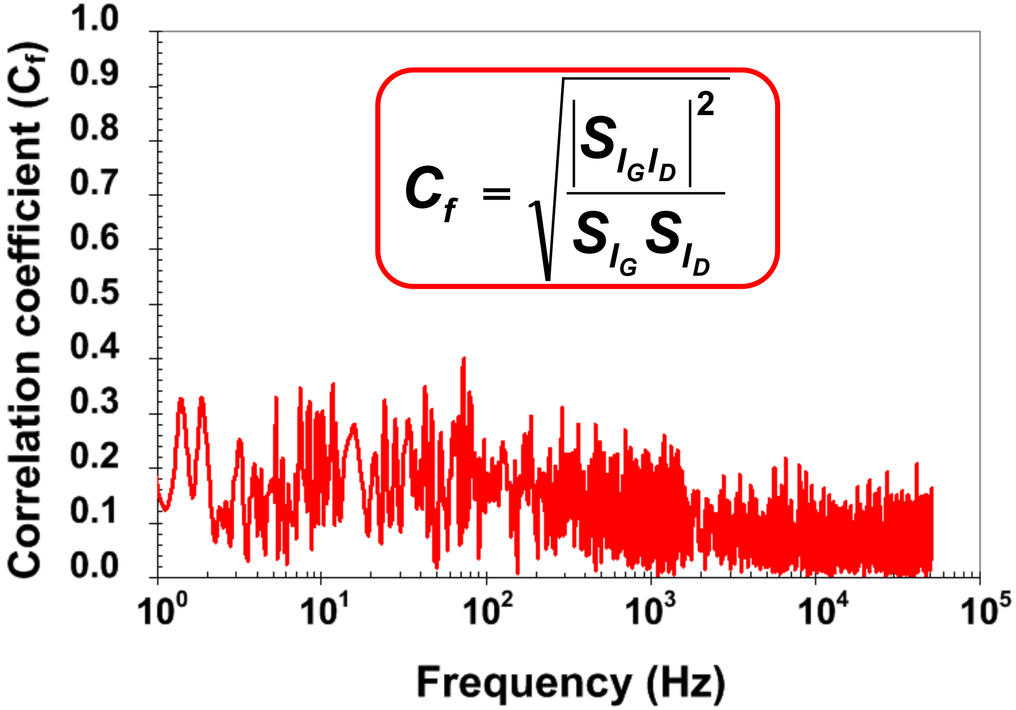
$$+ \frac{S_{RD}}{R_D^2}\left(\frac{R_D^2}{(R_G + R_D + R_{CH})^2}\right)$$

$$\because R_G >> (R_{CH} + R_D) \Rightarrow \boxed{\frac{S_{I_G}}{I_G^2} \cong \frac{S_{R_G}}{R_G^2}}$$

Gate stack noise dominant!!

- AC Short-circuited compact noise model.
- Gate current noise probing the gate stack quality.

Gate and drain correlation



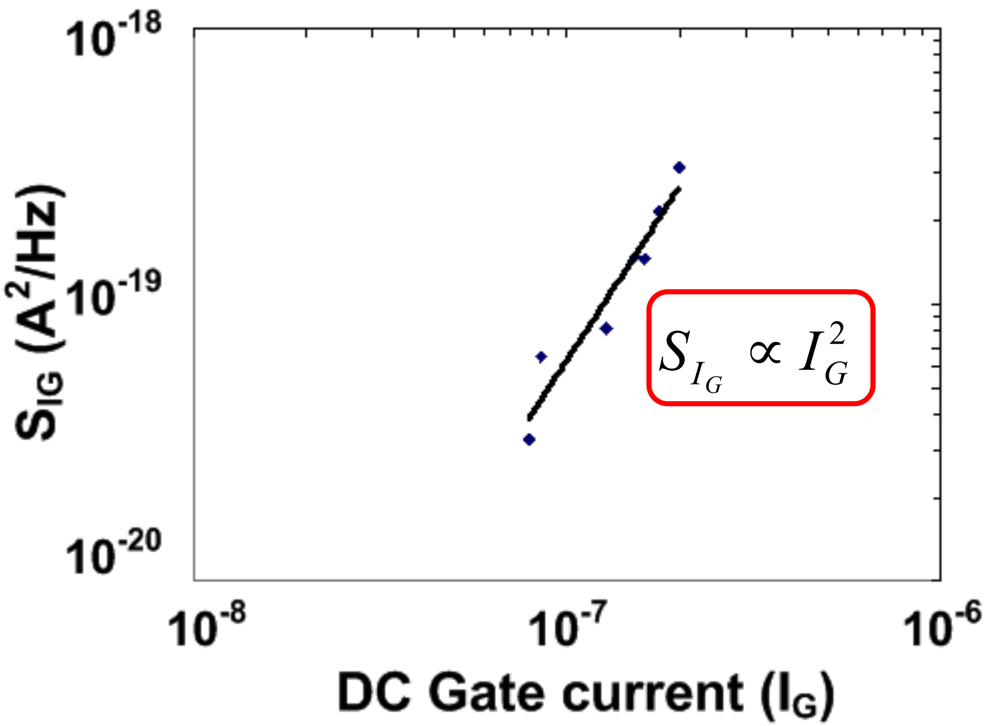
Gate noise: $S_{I_G}(f) = \frac{\overline{i_G{}^* i_G}}{\Delta f}$

Drain noise: $S_{I_D}(f) = \frac{\overline{i_D{}^* i_D}}{\Delta f}$

Cross-correlation: $S_{I_G I_D}(f) = \frac{\overline{i_G{}^* i_D}}{\Delta f}$

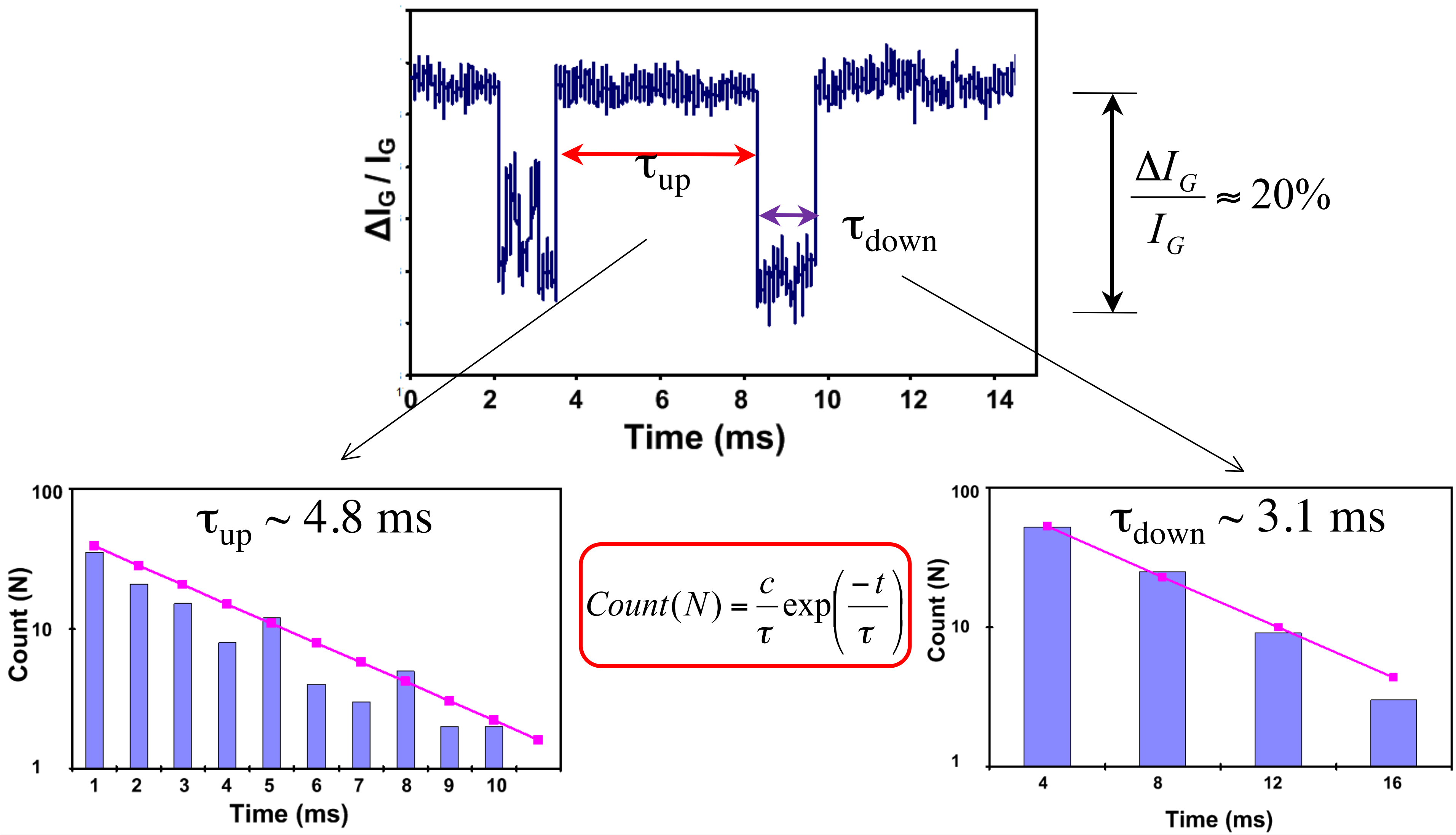
- Weak correlation between drain and gate current noise.
- Independent noise sources for drain and gate currents.

Gate 1/f noise



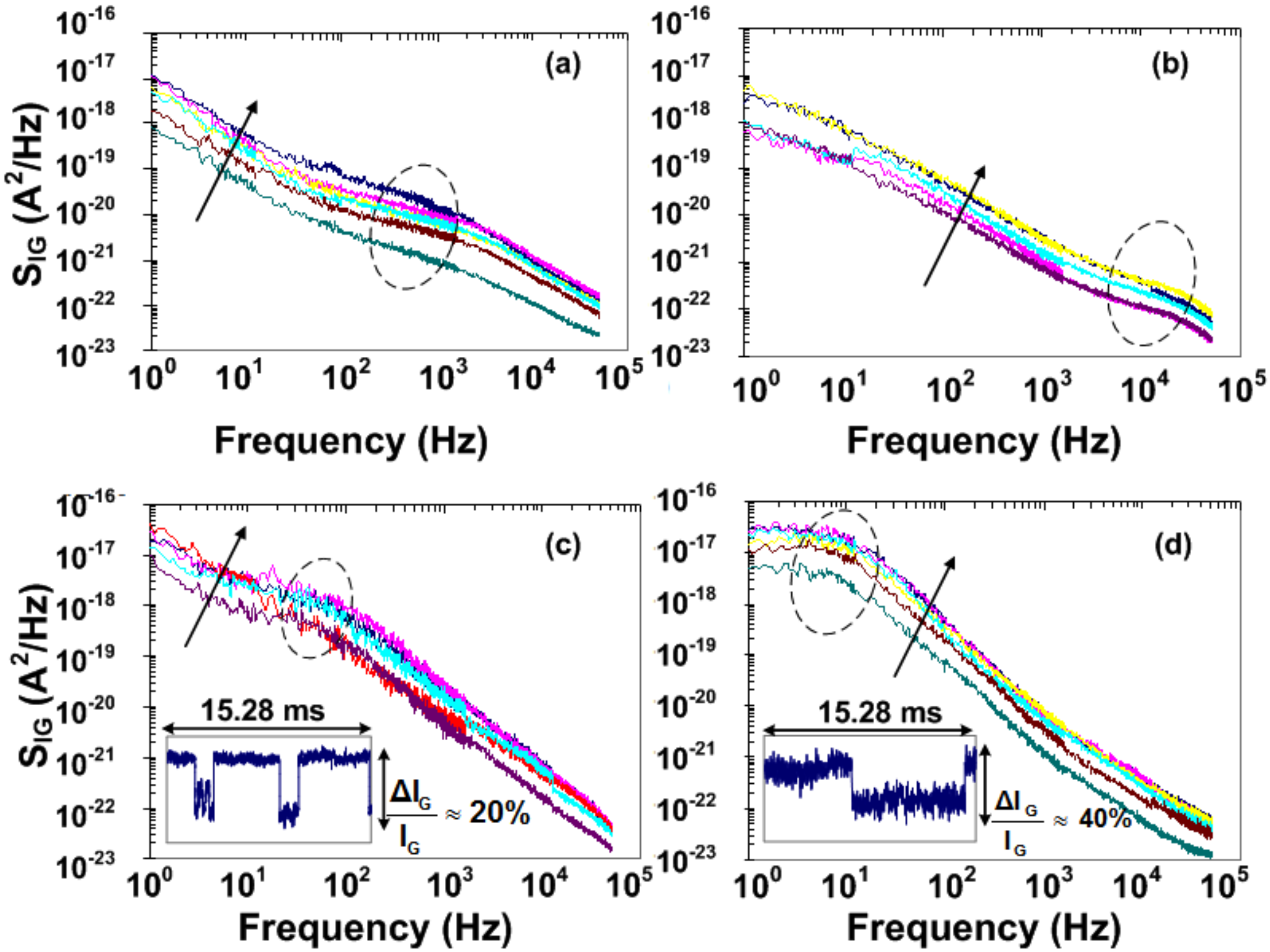
- Typical indicator of gate stack noise.
- Temporally stable 1/f noise with repeatable current dependence.

Gate RTS noise

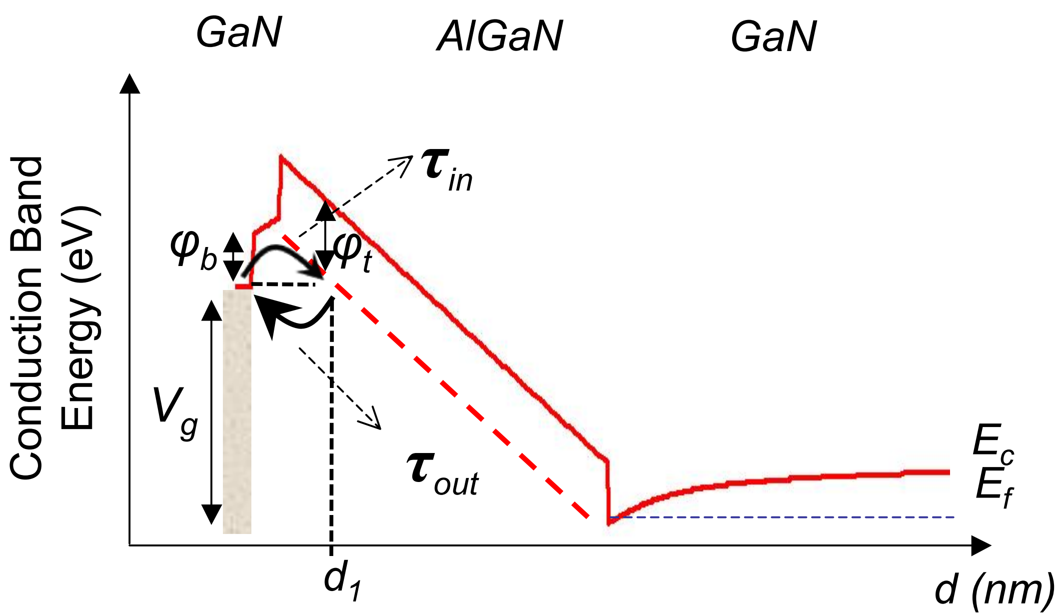


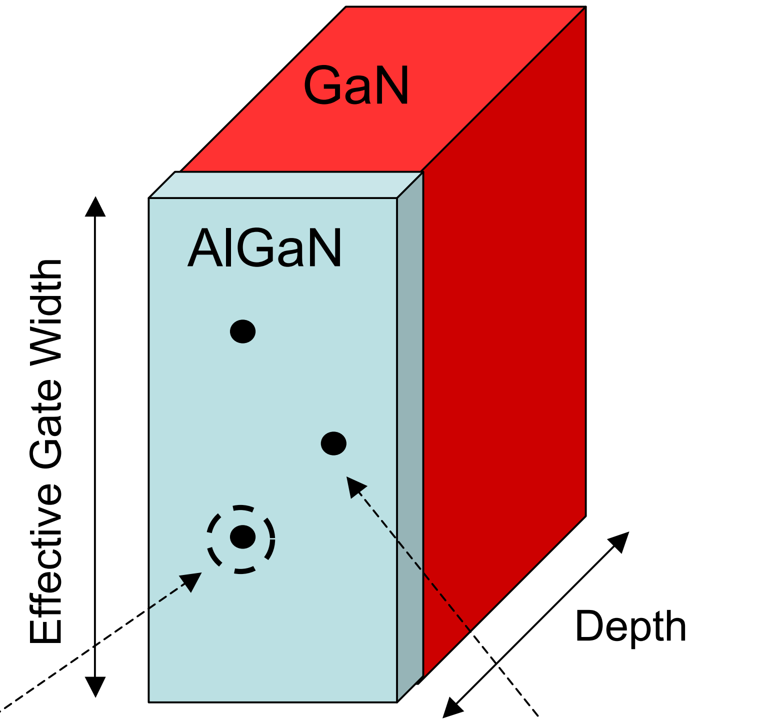
$$Count(N) = \frac{c}{\tau}\exp\left(\frac{-t}{\tau}\right)$$

Gate noise stability



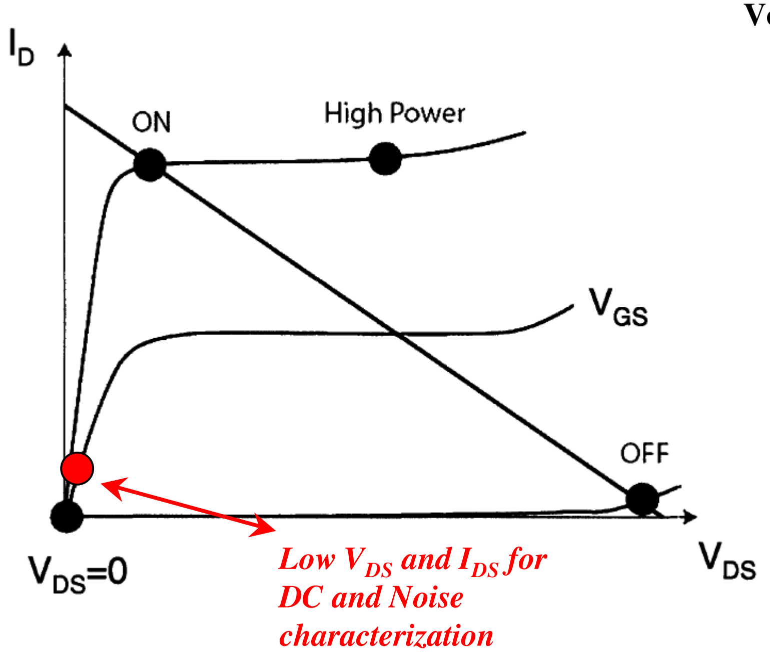
Gate noise model



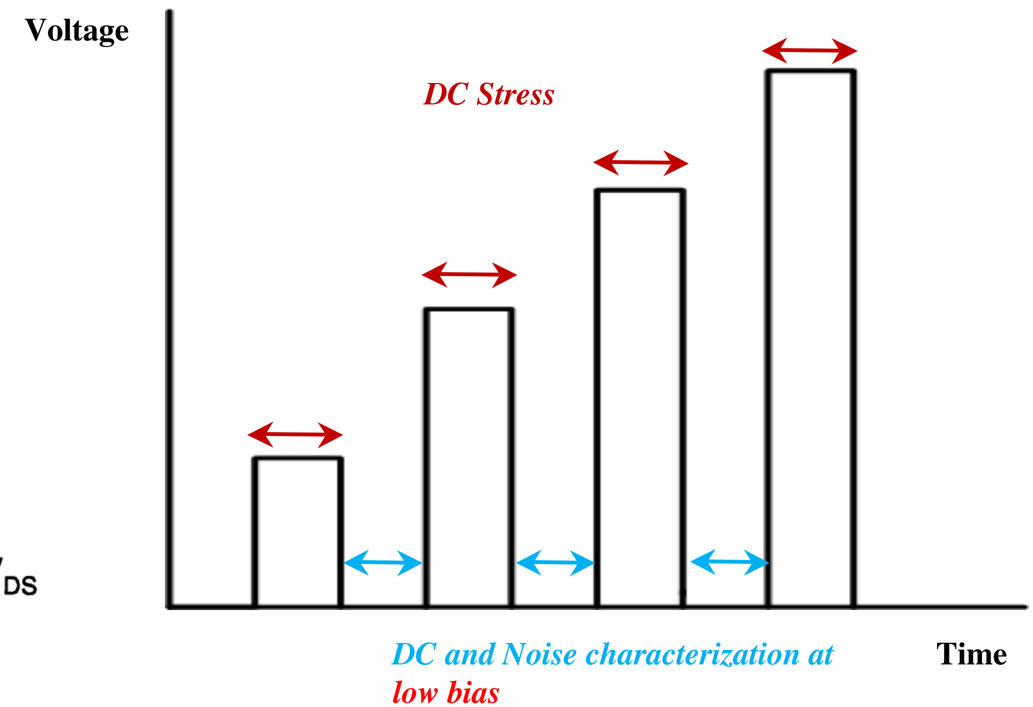


- RTS noise due to strong coupling of "trapping" "de-trapping" process to the localized leakage path.
- Lorentzian when weaker coupling of "trapping" "de-trapping" process.

Future Work



Ref. J. Joh, (2007)



- Noise a function of applied stress in three bias regimes to study hot carrier effects, inverse-piezo effects and coupled effects.
- Gate and drain noise evolution linked to physical location of degradation will give quantitative indicators of reliability.

Summary

- Noise setup upgraded for simultaneous measurement of gate and drain current noise.
- Channel is the dominant noise source with $\alpha_H \sim 10^{-3} - 10^{-4}$.
- Stable schottky contact is shown by the gate 1/f noise stability.
- Temporally unstable gate noise Lorentzians indicator of defect instability.
- Unstable defect located close to the gate metal semiconductor junction. Possibly in the interfacial layer.